From Pilot to Production: Practical Considerations in Your RFID Deployment March 26, 2007

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Who We Are

- Evaluate RFID products in a *scientific* way
- Provide useful, timely, credible, and unbiased data to end users of RFID products
- Constituents
  - **University of Kansas / ITTC**: Primary research contributor
  - **RFID Journal**: Initial funding, distributor, advertisement
  - **Rush Tracking Systems**: Initiator, industry lesion
- Business model
  - Sell reports (~$1,000 / report) to finance future reports
    - Look for release in April
  - Sponsorships
  - Research projects
- ITTC/KU Applied Research Labs solve hard problems
  - Direction of travel through portal w/ Seknion
  - Tagging metal assets
  - Passive sensor tags
- Intellectual property
  - 4 patents pending
  - 2 Licenses signed
    - Product available in 2Q07
  - More in the pipe
- Basic research
  - RFID privacy using CDMA

Big Picture

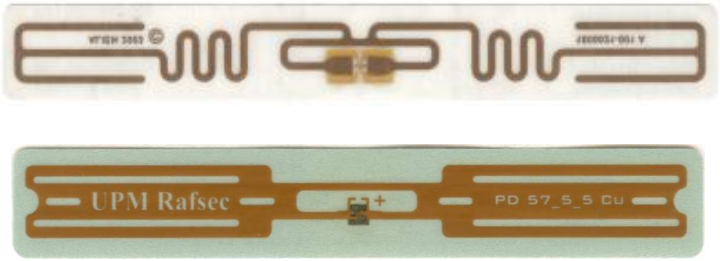
- What factors affect whether RFID will work for you:
  - Cost
    - Tags and readers small part
  - Performance
    - How far, how fast
  - Reliability
    - Nothing in life is 100%
  - Robustness
    - Will it survive
  - Environment
    - Noise, obstacles, other readers, RF equipment
  - Longevity
    - Battery life
    - Wear-and-tear
- Integration
  - Will it work with your information systems
- ROI
  - How much, how soon
- Support
  - Can I support the technology in 5-10 years?

Focus

- Present *technical* aspects to making tags, readers work
- Take home:
  - How the different technologies work
  - What impact the environment has
  - When to use different technologies
  - What to expect from RFID systems
  - Where the future is headed

Outline

- A brief lesson in physics (electromagnetics)
- An overview of the technologies
  - According to frequency
  - According to capability
- Focus on UHF
  - Tags
  - Readers
  - Looking forward



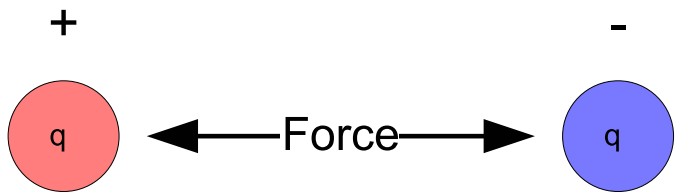
A Brief Lesson in Physics (Electromagnetics)

Outline

- Coupling via three modes:
  - Electrostatics
  - Magnetics
  - Electromagnetics

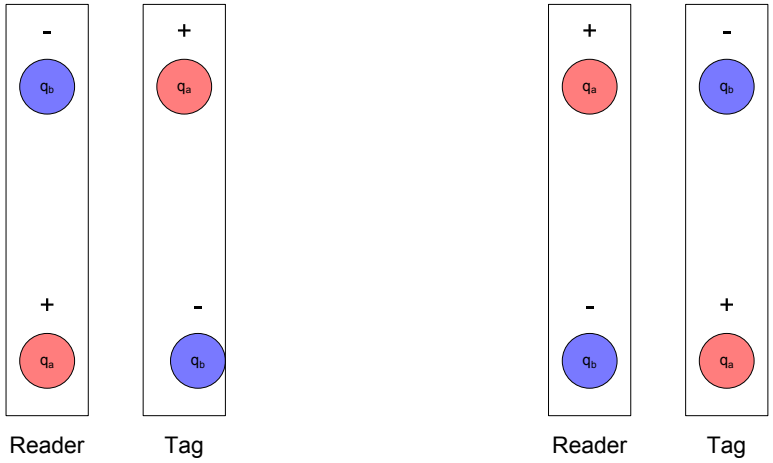
Electrostatics

Opposites attract
(and likes repel)



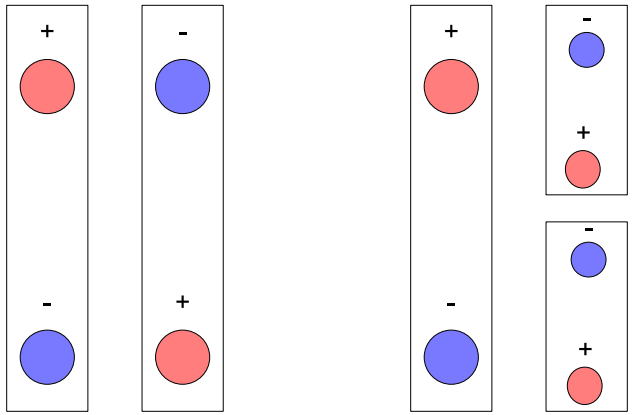
$$F = k_c \frac{|q_a||q_b|}{d^2}$$

Power Transfer



- By changing distribution of charges on reader antenna, you can force charges to move in the tag
- Communicate by modulating the flow of charges over time

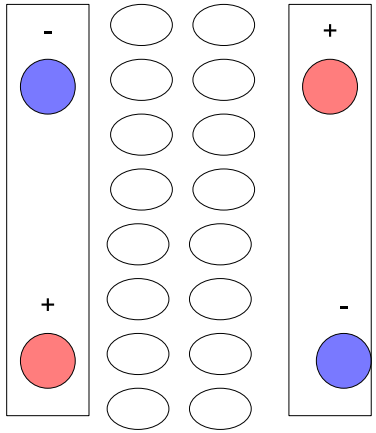
Backscatter Communication



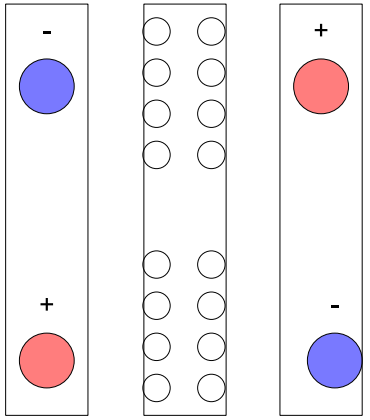
- By interrupting the flow of charges, tag can communicate back to the reader
  - Reader senses that it is harder to separate charges on its antenna

Properties of Electrostatic Coupling

Dielectric material
enhances performance



Intervening metal has
little affect



Summary

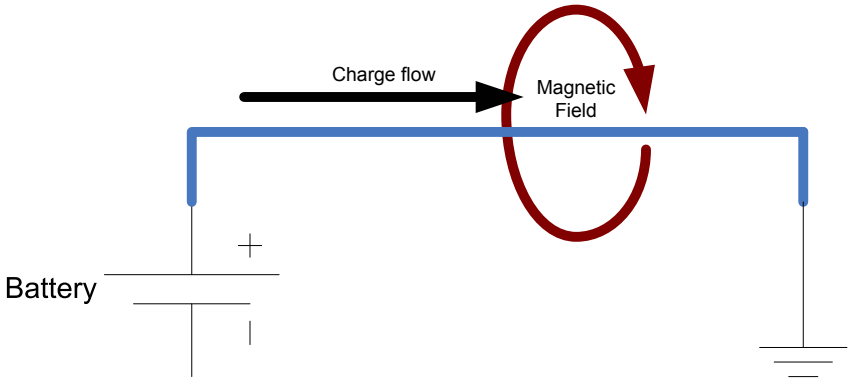
- Electrostatic coupling:
  - Works over very short distances (mm)
  - Enhanced by dielectrics
  - Little affect by intervening metals
  - Requires low frequencies for operation (HF)
- Products:
  - Virtually none

Magnetics

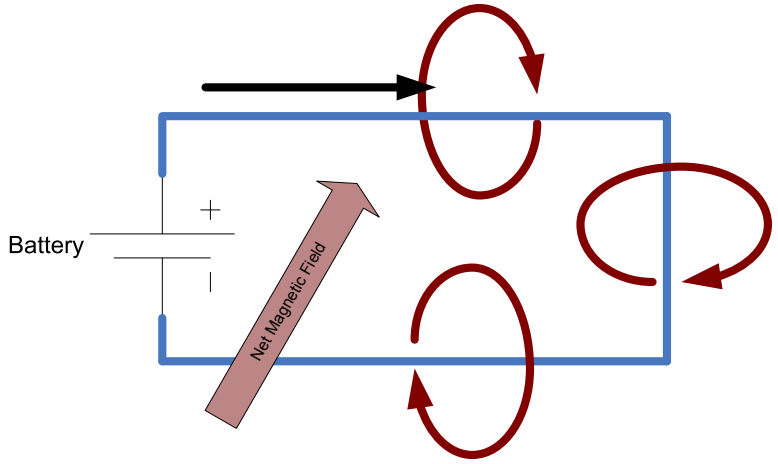
- Moving charges create a magnetic field

$$\boldsymbol{B} = \boldsymbol{v} \times \frac{\boldsymbol{E}}{c^2}$$

$$\boldsymbol{F} = q\boldsymbol{v} \times \boldsymbol{B}$$

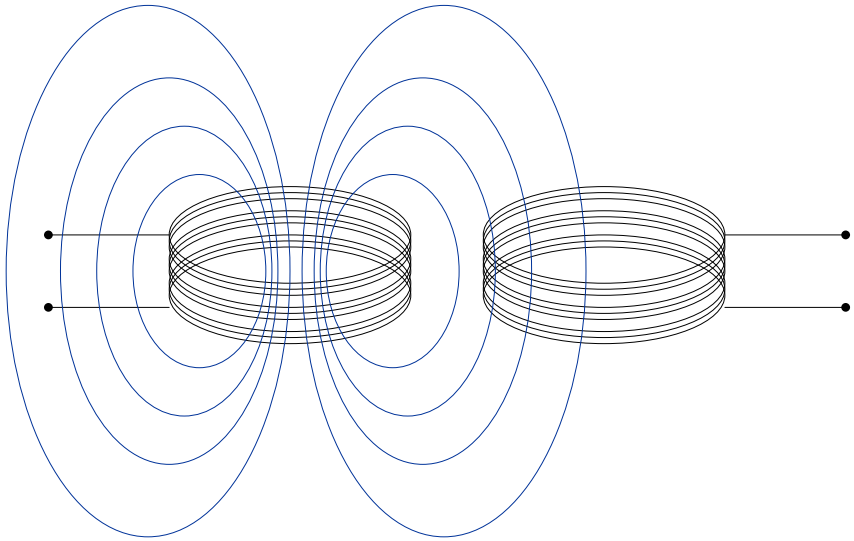


- Loops "focus" magnetic fields like a lens



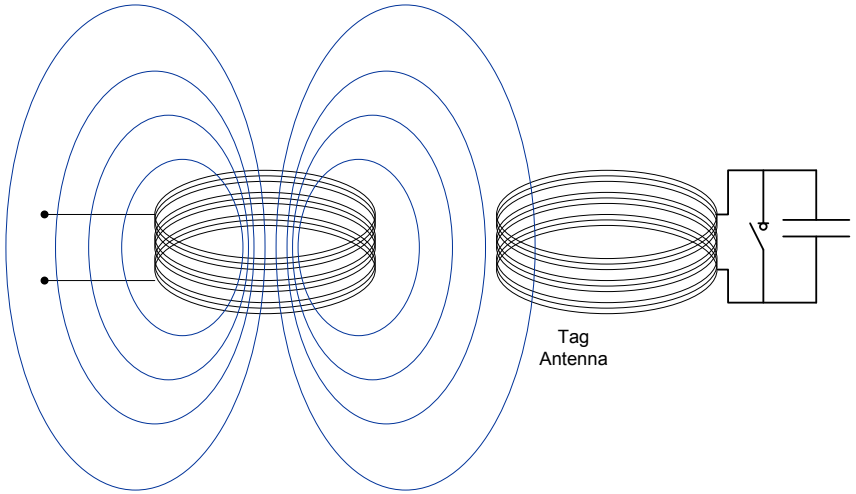
Power Transfer

- Two loops can be coupled when
  - H lines of one loop flow through another loop
  - Described by k, can be as low as 0.01
- Just as I (current) induces H, H induces I
  - How power transfers from reader to tag



Communication

- Tag to reader
  - Tag current creates H, induces I on reader antenna
  - By varying tag I, can vary I in reader
  - (Capacitor used to “tune” the antenna for optimal efficiency)



Properties of Magnetic Coupling

- Magnetic fields *not affected* by dielectrics (e.g., water)
- Magnetic fields *blocked* by metals
  - Limited penetration at lower frequencies
- Dielectrics near tags can still cause problems
  - Changes resonant frequency of antenna
  - Dielectric loss can reduce efficiency
- Metals near tags cause problems
  - Change resonant frequency of antenna
  - Reduces efficiency

Summary of Magnetic Coupling

- Commonly use loop antennas
- Magnetic *fields* not affected by dielectrics (e.g., water)
- Antennas *are* affected by dielectrics
- Magnetic fields blocked by metal
- Metal near tag antennas cause problems
- Frequencies: low through very high
  - Reduced read distance with higher frequencies
- Read distance: mm to m

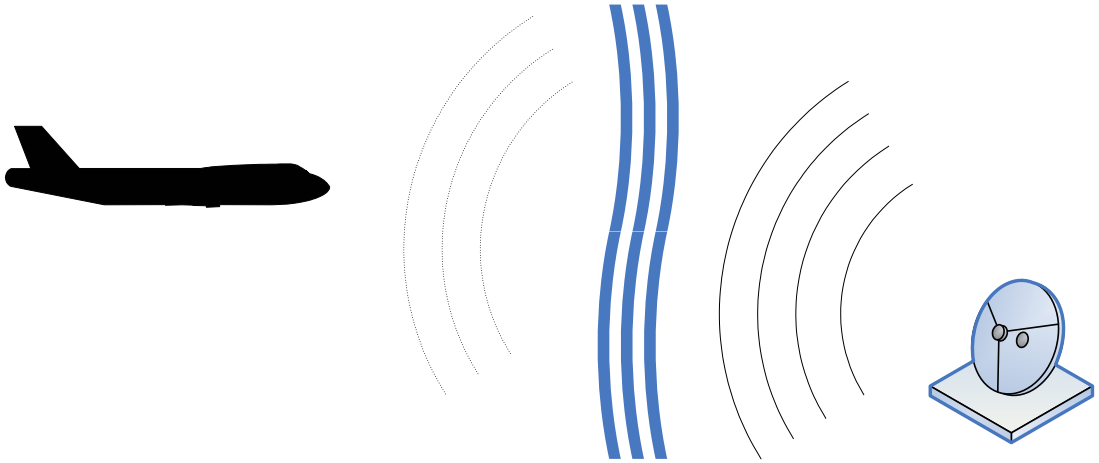
Electromagnetics

- Think: *radar, light*
- Typically for high frequencies (short wavelengths) and/or long distances

Power Transfer

- Waves carry the power
  - Solar cells turn light to electricity
  - Microwave ovens turn 2.4 GHz RF into dinner
  - Induces currents on a wire, similar to electrostatics

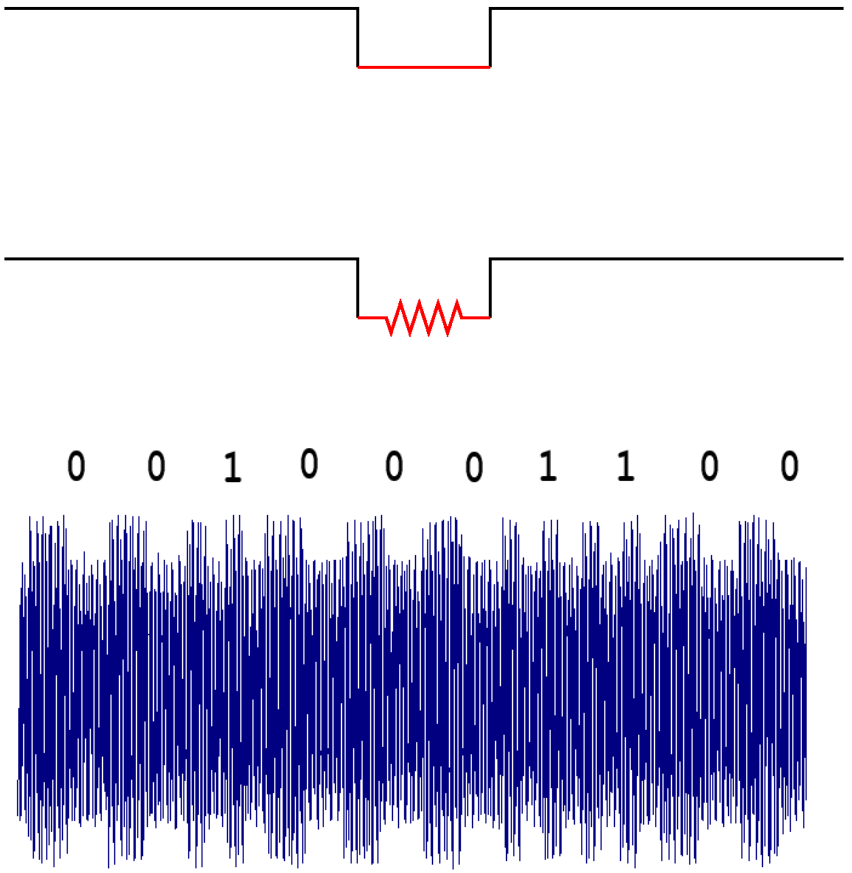
Affects of Material



- Materials readily interfere
  - Metal reflects, water absorbs
  - Some materials reflect some and absorb some (e.g., tinted glass)
  - Some are mostly transparent (foams, simple plastics)

Backscatter Communication

- Tag modulates RCS
- Short (or open):
  - large RCS
- Matched load:
  - power → heat
  - smaller RCS
- Binary modulate RCS over time
  - ASK, FSK, etc.



Active Tags

- Only enough power transfer to communicate

- No backscatter
  - Transmit / response

Comparison of Capabilities

	Passive	BAT	Active
RF output	30 dBm	30 dBm	20 dBm
Modulation correction	0 dB	-3 dB	0 dB
Reader Gain	6 dBi	6 dBi	0 dBi
Path loss: 3 meters	-41 dB	-41 dB	-41 dB
Receiver antenna gain	2 dBi	2 dBi	0 dBi
Received power	-3 dBm	-6 dBm	-21 dBi
Necessary power	-11 dBm	-42 dBm	-70 dBm
Margin	8 dB	36 dBm	49 dBm
Estimated range	7.6 m	192 m	862 m

Summary of Electromagnetic Coupling

- Long distance communication
- Sensitive to intervening materials
  - X-ray reads generally require BAT, active tagging
- Materials tend to de-tune antennas
- Frequencies: 300 MHz +

Summary of Technologies

Frequency

- Low Frequency (LF)
  - 125—135 KHz (long wavelength)
  - Near-field only (usually inductive)
  - Passive used for animal, near-contact industrial
  - Active LF tags being developed (IEEE 1902.1 “Rubee”)
- High Frequency (HF)
  - Typically 13.56 MHz
  - Inductive near-field passive only
  - ISO 14443, 15693
- Ultra-High Frequency + (UHF, microwave)
  - 433 MHz (active), ~900 MHz, 2.4 GHz (passive, active)
  - Usually electromagnetic coupling, some near-field UHF
  - IS0 18000-6c “Gen 2”

Functionality

- Passive (e.g., ISO 18000-6c)
  - No internal power source
  - Short distances
  - Low cost
- Battery-assisted (e.g., Intelleflex)
  - Battery powers circuit, not communication
  - Moderate distances
  - Moderate costs
- Active (e.g., ISO 18000-7 WIP)
  - Battery powers circuit, communications
  - Longer distances
  - Higher costs
- Sensing
  - Requires active tags
  - E.g., temperature, impact, sound, light, GPS, LPS, etc.
- Interrogating
  - “Tags” interact as peers
  - “Ad hoc networks”
  - E.g., 802.11, Bluetooth, Zigbee, etc.

Supply Chain Management

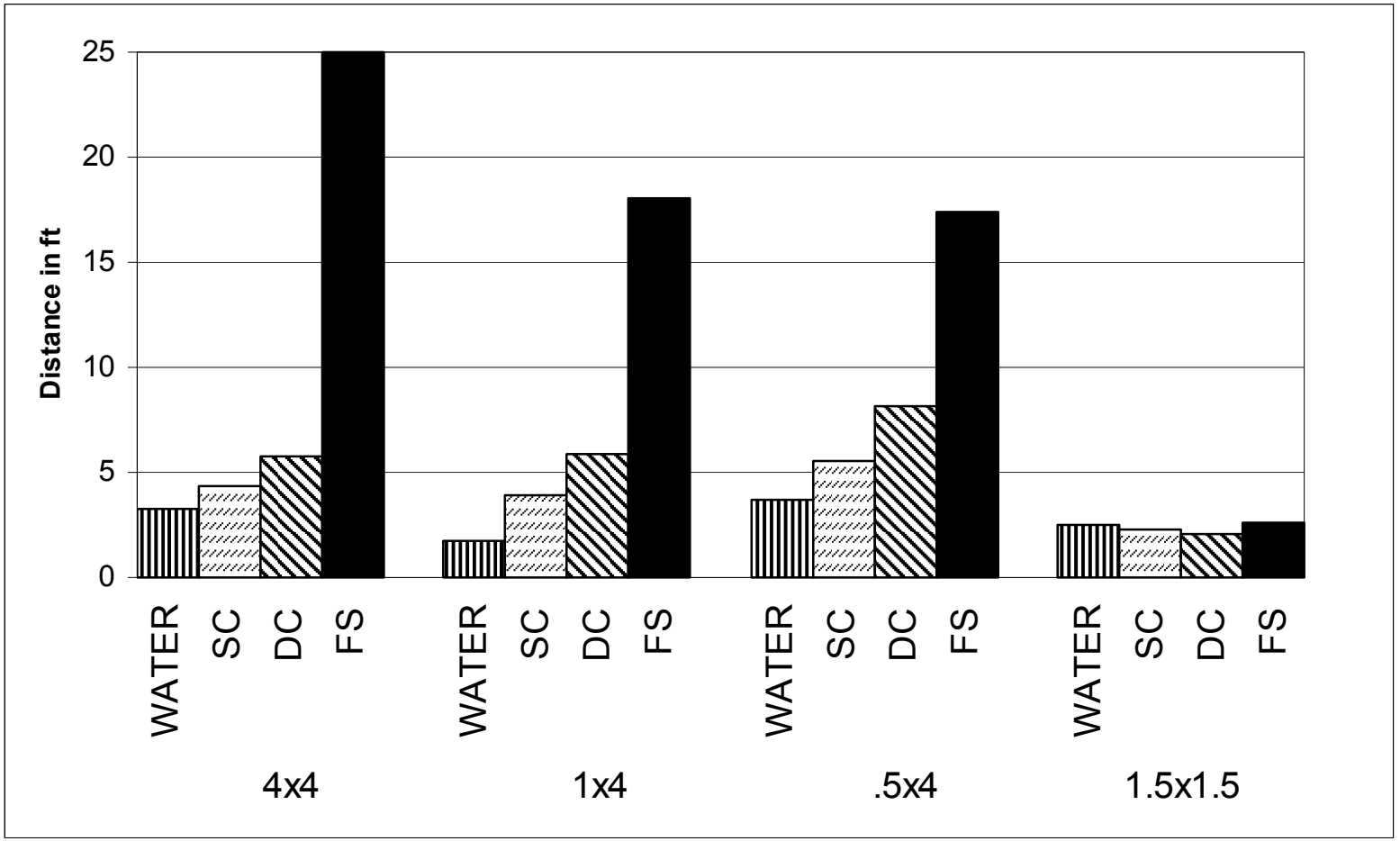
Supply chain has focused on passive, active UHF

- Dock doors demand “feet” of read distances
- Temperature-aware requires active, data logging
- Cold temperatures can create demanding environments
  - Frequently tagging liquid contents
  - Frost / moisture from environment
  - Temperature can interfere with adhesives

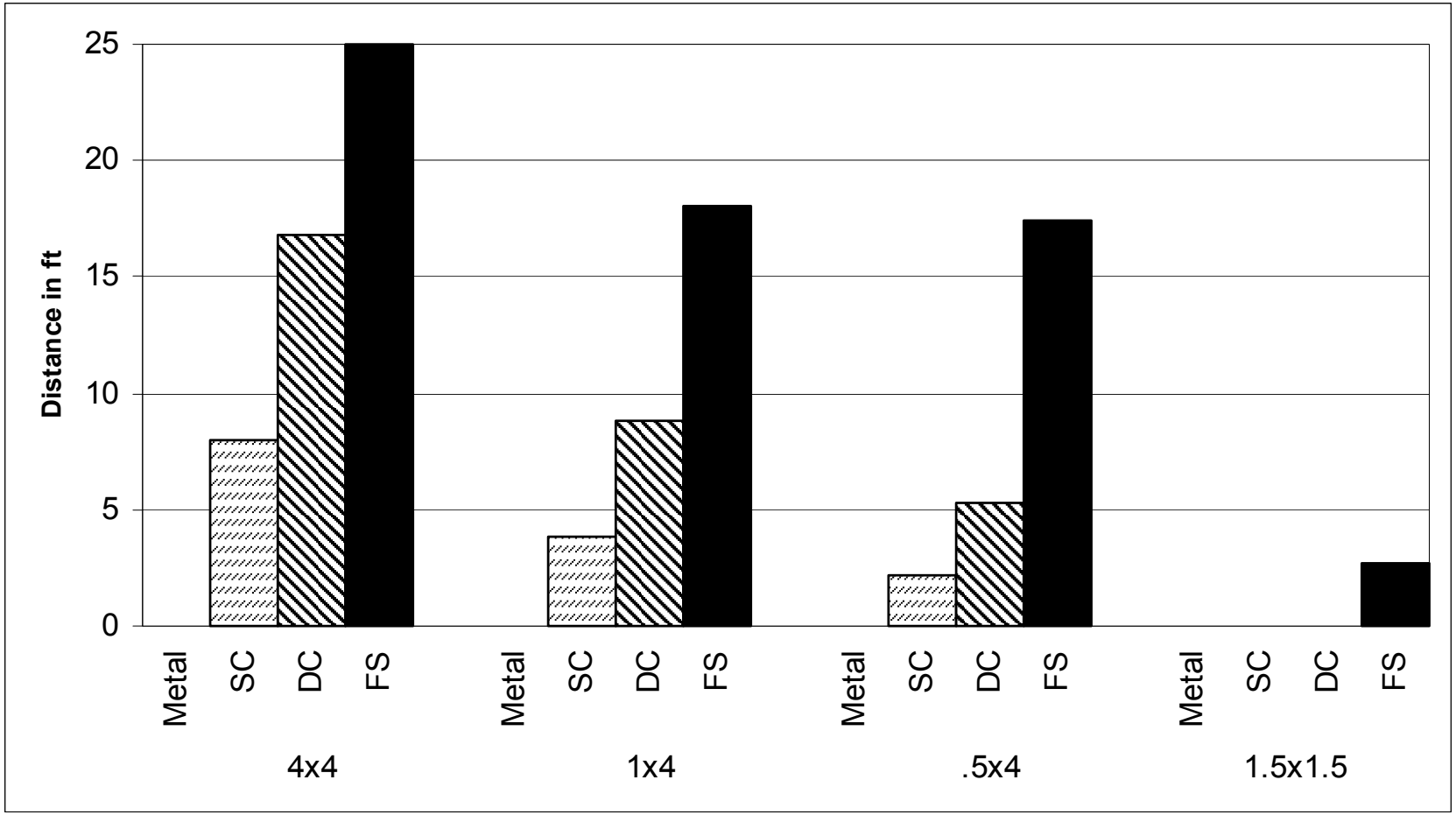
Factors with Passive UHF

- What are you tagging
  - Metal, water give problems
- What tags to choose
  - Impacts performance, cost
- How to select a reader
  - Impacts cost, bulk, complexity
- How to get the most out of your tags

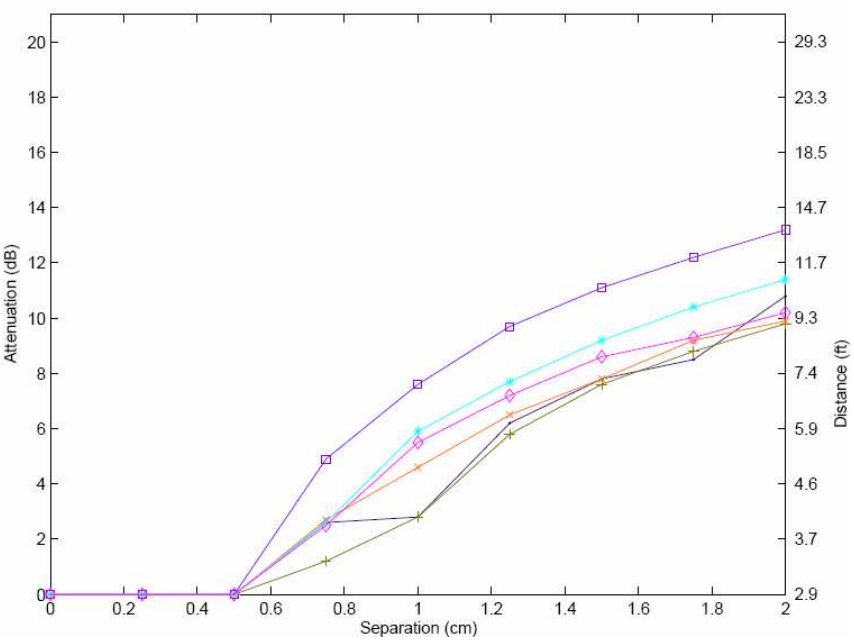
Water Degrades Performance



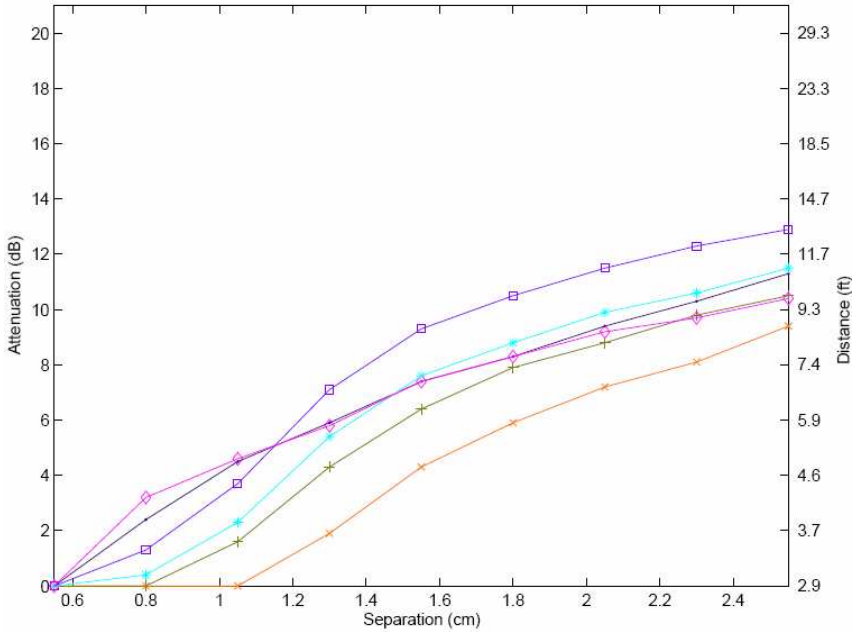
Metal Degrades Performance



Experimental Data: Tag Performance vs. Separation

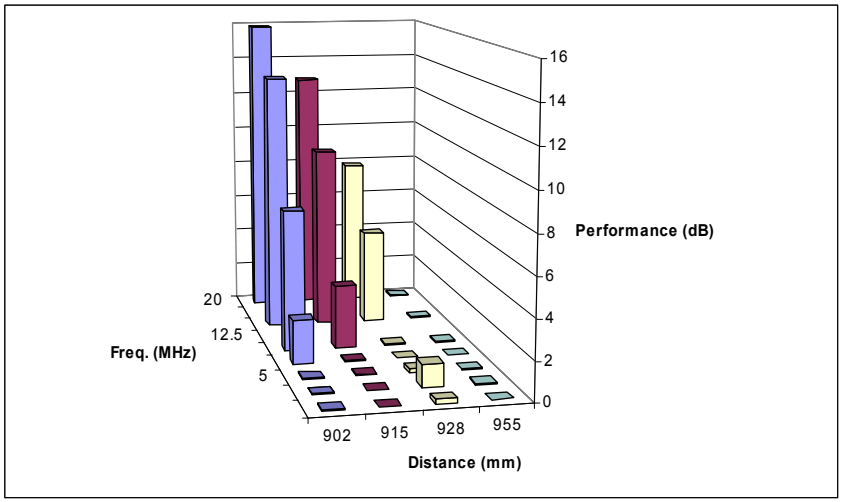


Separation from Metal

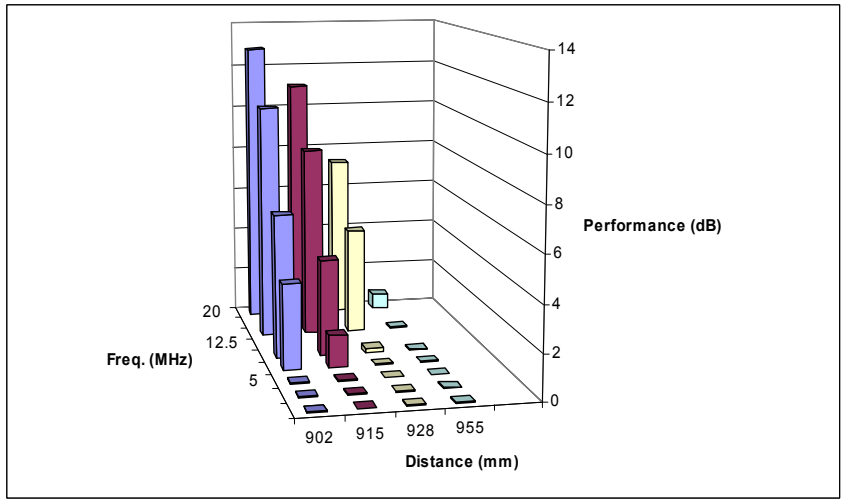


Separation from Water

Experimental Data: Tag Performance vs. Separation

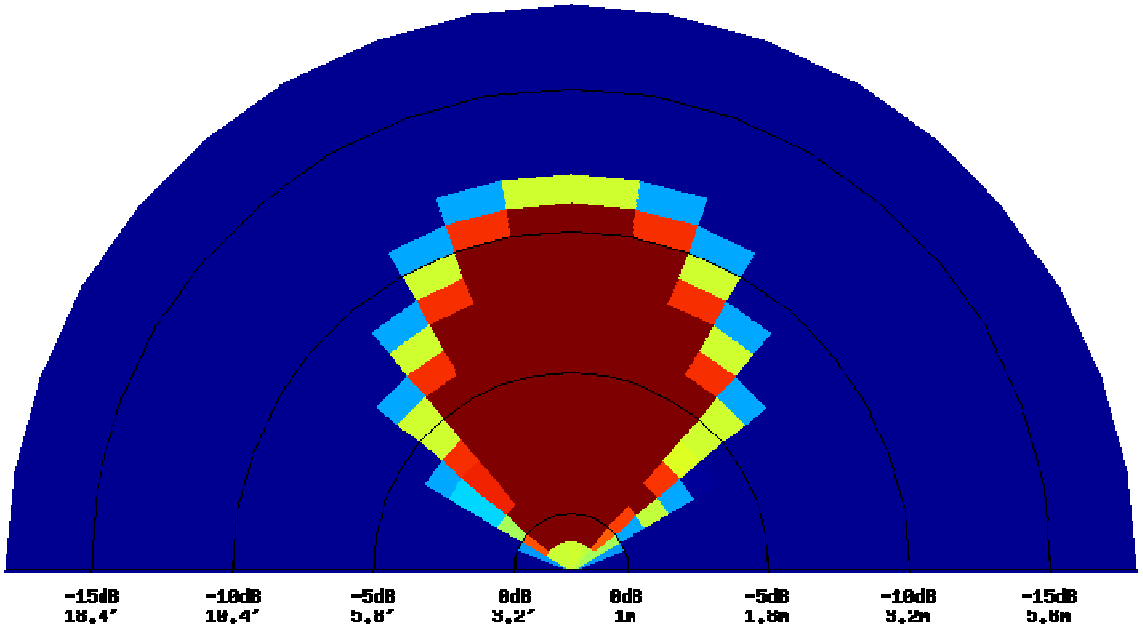


Separation from Metal

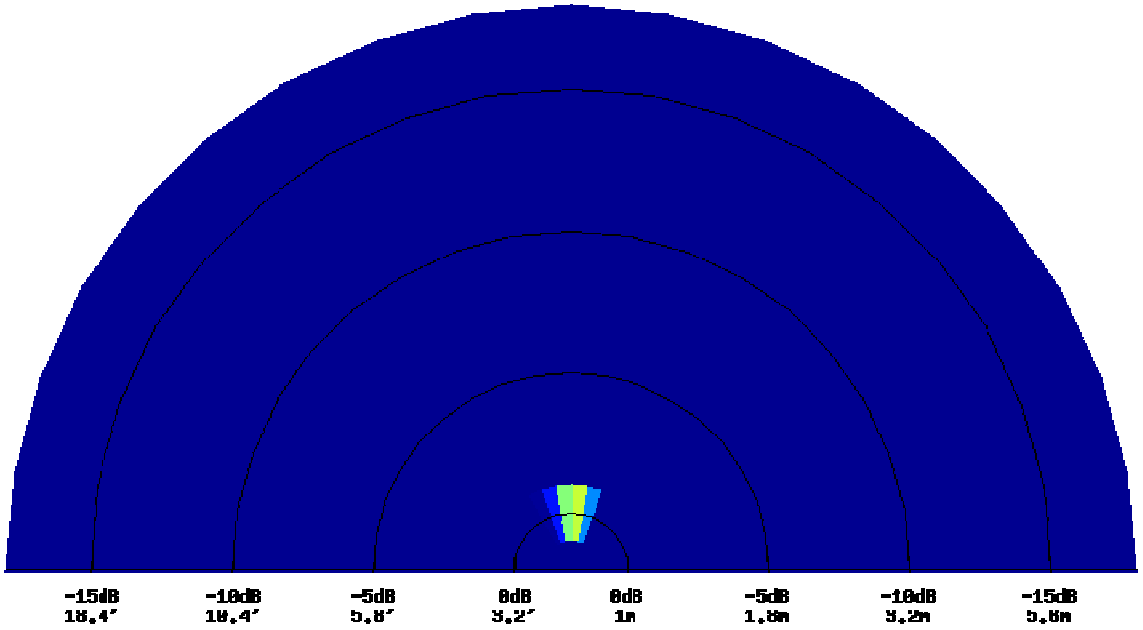


Separation from Water

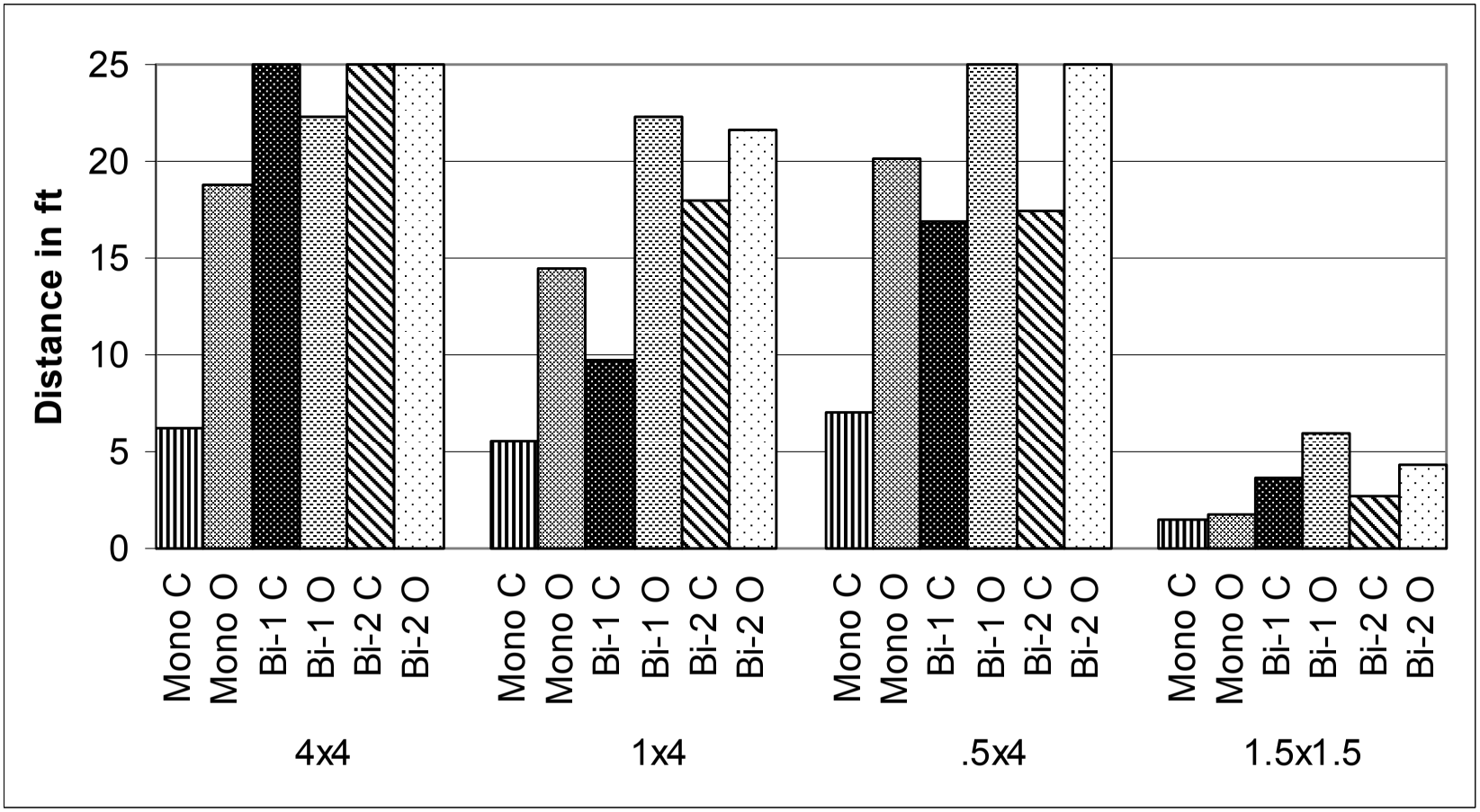
Metal Changes Orientation Sensitivity of “Omni” tag



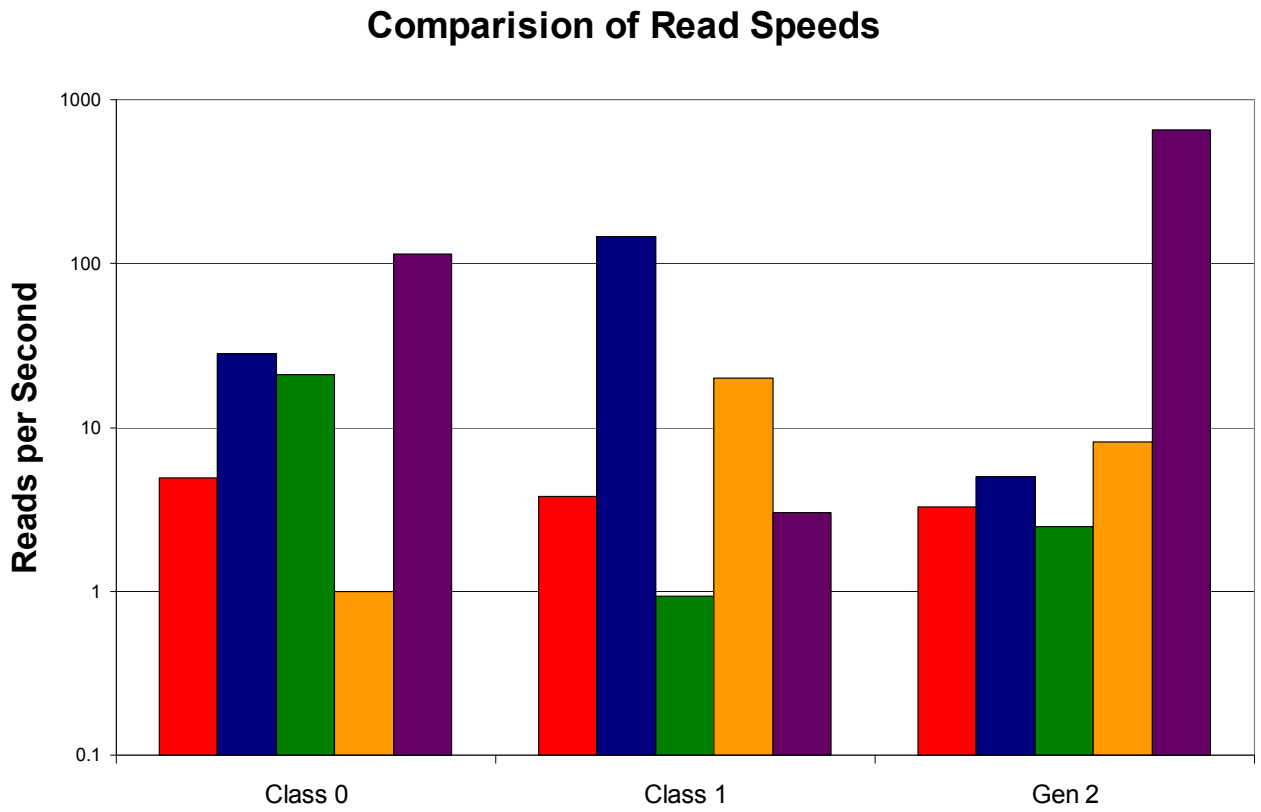
Some tags *crippled* by metal



Environment Degrades Performance



Different Readers Read at Different Speeds



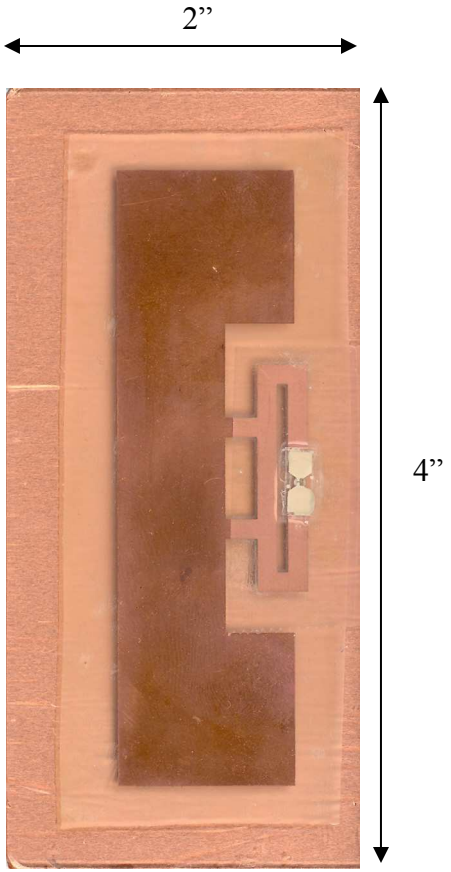
Need Performance?

Lessons learned:

- Larger tags generally mean more performance
- Stay away from metal, water
- Use bi-static antennas / readers for long reads
- When all else fails, go active
- For sensing, you *need* active tags

Developments from KU

- 4 patents pending
- Manufacture agreement signed 3/23/07
- Rugged 2x4x.06” form factor
- UV / Abrasion coated
- Externally validated: 20’ read distance on water, industrial environment



Future Technologies from KU

- High-performance “credit card” work-on-metal tag
- Work-on-metal, work-on-air low-cost foam spacer tag
- Rugged “stick” asset tag
- Low-cost sensing passive RFID tag

Future Technologies

- Tags:
  - Increased read distance
  - Increased reliability
  - Lower cost
- Readers:
  - Increased performance
  - Smaller packages
  - Lower cost
- Sensors:
  - Increased capabilities
  - Better / smaller / cheaper batteries

Conclusions

- For dock door use case: need UHF tags
- Passive tags:
  - Stay away from metal, water
  - Size matters (usually)
  - Use KU-tag (or other specialty tag) for hard-to-tag items
- Readers: Two antennas = better performance
- Sensing: active tags
  - +Orders-of-magnitude more margin
  - -Cost